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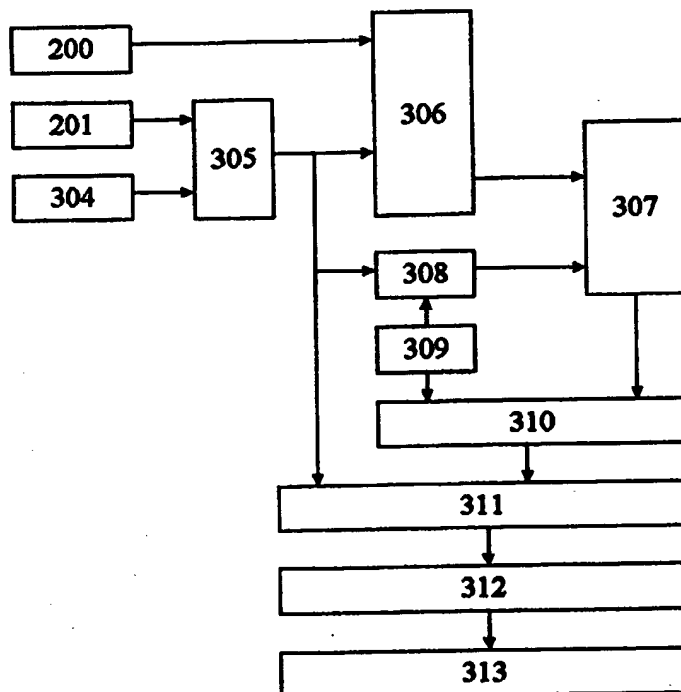
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(54) Title: MEASUREMENT SYSTEM

(57) Abstract

A system for monitoring the supply of a commodity (in particular, electricity) using a physical distribution system consisting of at least one input and a plurality of outputs and determining the deemed consumption of one or more outputs during a period. The system includes means to determine the overall demand, that is the total commodity supplied into the network, during an extended period, and the deemed consumption of outputs during the same extended period. The system further includes means to determine the deemed consumption during an extended period of a group of outputs without reference to the individual consumptions of those outputs. The system includes a means to apportion the deemed consumption of outputs, including groups of outputs, to sub-periods of the extended period and to adjust the apportioned consumption without causing a cumulative error over the extended period, such that the aggregate deemed consumption in any one sub-period equals the overall demand in that sub-period.



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Measurement System

Electricity, gas and many other commodities are generally provided on a per unit charge, where the unit of measurement depends upon the commodity in question, and some form of metering is generally used to measure the number of units consumed by the user, that is the consumer.

Frequently, the cost to the consumer of the commodity can be simply calculated by multiplying the charge per unit by the number of units consumed. In addition to the per unit charge there may also be additional charges included fixed charges.

For commodities such as electricity, consumers purchase the commodity from a retail company. The cost of the commodity to the consumer includes the cost of generating or producing the commodity and the cost of delivery. For example, in electricity supply a generating company produces the electricity that is delivered to the consumer by means of a physical network. In the case of electricity, generation and delivery are increasingly provided separately from the retail supply, that is the charging to the consumer. In such circumstances the retail company that provides the retail supply has a commercial relationship with the consumer, including billing the consumer for consumption, and the retail company then pays for the electricity on a wholesale basis.

In some countries, competition has been introduced in the supply of commodities such as electricity. Such competition enables consumers to choose which retail company they wish to purchase the commodity from. In the case of electricity, there may be several generators, and each generator must be paid for the electricity that they produce. This involves a form of wholesale market or "pool" being established for the generation of the commodity, such that the wholesale price, that is the price paid to generators, is defined for finite periods of time, referred to herein as Accounting Periods. Generally, Accounting Periods are relatively short periods of time, and are commonly half-hour or one hour periods. To determine the amount owed to a generator, it is necessary to determine the price to be paid to the generator and the quantity produced by the generator in the period in which the price is valid. In general this is achieved by using sophisticated metering at the generator to determine the quan-

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tity produced in each Accounting Period. Such metering is capable of recording data for each Accounting Period and is referred to herein as interval metering.

The amount owed to a generator may be payable by several retail companies in varying proportions. In order to determine a wholesale charge to the retail company, for either generation or delivery or a combination of generation and delivery, it is essential to know the price (that is, the applicable wholesale price), and the quantity of the commodity for which the retail company is responsible. Such wholesale charges to the retail company are referred to herein as the Supplier Charges. There are two prior art means of determining the Supplier Charge.

The first means involves the use a suitable form of interval metering at consumers such that the consumers' individual consumption is recorded in each Accounting Period. This enables the Supplier Charge to be determined; it is then paid by the retail company.

In this first prior art means, when determining the Supplier Charge, the values of the consumer's metered consumption are generally adjusted for an estimated value of loss from the physical distribution network. Adjustment for loss can be performed by multiplying the consumption by a estimated loss factor which will scale the consumption for an estimate of loss. Thus, for example, if 5% of electricity is lost in delivery, then the loss factor could be 1.05 and the Supplier Charge will be determined by multiplying metered consumption by the loss factor and the price.

A simple arrangement of this first means may be that a generator produces electricity which is metered at the generator on a half-hourly basis and the generator sets a half-hourly price. Interval metering is also installed at consumers. It is therefore possible to determine the total amount owed to the generator by multiplying the generators price by the half-hourly quantity of electricity produced. A charge to each retail company can be determined using the half-hour consumption of each retail companies' consumers multiplied by the corresponding price.

The second means enables consumers to have relatively simply metering equipment that does not record the consumption during individual Accounting

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Periods. Rather, the metering equipment at the consumer can record the consumption during relatively long periods.

Patent applications WO 95/26065 (PCT/GB95/00636) and WO 97/06442 (PCT/GB96/01937) provide means to determine a value of consumption, the deemed consumption, in each Accounting Period irrespective of the metering used at the consumer. Such systems have become known as Profile Settlements, and the method of determining the deemed consumption has become known as profiling. The value of Deemed Consumption may or may not, depending upon implementation, include an estimate for the losses resulting from the distribution of the commodity. If Deemed Consumption does include an estimate for losses, then it is achieved by a scalar loss factor as described above. Within Profile Settlements it is also possible to use interval metering at some consumers, particularly those consumers with a large consumption.

During the first stage of Profile Settlements, the metered consumption for a consumer for a period, the Metered Period, is apportioned to the Accounting Periods within the Metered Period to provide a value of Deemed Consumption in each Accounting Period. For a particular consumer, the aggregate Deemed Consumption for all Accounting Periods in their Metered Period equals the metered consumption during that period. For example, a particular consumer may be metered over a one month period and the metered consumption for that metered period, that is to say the month, can be apportioned to half-hour periods such that in the month the sum of the half-hourly values of deemed consumption equals the metered consumption. The method of apportioning the consumption to Accounting Periods uses a profile consisting of a set of profile weightings, with one weighting per Accounting Period. Within Profile Settlements there may be a number of such profiles, each representing a type or class of consumption behaviour. The consumers sharing a particular profile are referred to herein as a profile class.

Profile Settlements enables a Supplier Charge to be determined for an Accounting Period in respect to the consumption of a consumer or group of consumers. Using Interval Metering or Profile Settlements, it is therefore possible to determine a value of deemed consumption for each Accounting Period.

As described above, Interval Metering frequently exists or can be installed at the source of the commodity. For electricity and other commodities, there is

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a physical delivery means to supply the commodity to the consumer. In the case of electricity the delivery means consists of one or more distribution networks. On a national basis these distribution networks are sometimes connected to the generation locations by means of a transmission network; that is, a higher capacity form of distribution network. Within this delivery means it is possible to arrange for a suitable form of Interval Metering to measure the amount of the commodity supplied into a defined part of the distribution and/or transmission network. This metering can be arranged to record the amount of the commodity during periods, for example during Accounting Period. Where there are multiple inputs to the defined part of the network, then each can be similarly metered. The metered part of the network will supply a plurality of consumers. Thus the total quantity, representing the consumption by the associated consumers, is known for each Accounting Period and is referred to herein as the Overall Demand.

There are two main forms of Profile Settlements commonly referred to as Difference Profiling and Global Profiling.

In Difference Profiling there is an incumbent or default retail company. Using interval metering or profiling, it is possible to determine a value of deemed consumption in each Accounting Period for all consumers supplied by retail companies other than the incumbent. These values of deemed consumption can be adjusted for loss, by multiplying the value of consumption by the estimated loss factor, and can be aggregated for each Accounting Period. In each Accounting Period the aggregate consumption can then be deducted from the Overall Demand and the remainder can be considered to be the consumption in each Accounting Period for all consumers supplied by the incumbent retail company.

Global Profiling on the other hand requires the interval metering or profiling to be used to determine a value of deemed consumption for all consumers for each Accounting Period.

Global Profiling can be used to produce an aggregate value of consumption for all consumers for each Accounting Period. The prior art also includes means to then adjust the values of consumption such that in aggregate the consumption in each Accounting Period equals the Overall Demand. This method of adjustment is known as Compensation.

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Compensation is achieved by a number of steps. First, the loss adjusted consumption in each Accounting Period that is measured using interval metering at consumers is subtracted from the Overall Demand, producing a Residual Demand. Then, using profiling, the aggregate deemed consumption for the Accounting Period is determined for those consumers without interval metering; this is referred to herein as the Profiled Demand. A Compensation Factor is produced for each Accounting Period by dividing the Residual Demand by the Profiled Demand. Each value of deemed consumption produced using profiling is then adjusted by multiplying it by the Compensation Factor. The result is an adjusted value of consumption whereby the aggregate of such values equals the value of Residual Demand.

The result of the prior art method of compensation is that the sum of interval metered consumption and adjusted Profiled Demand equals the Overall Demand. However, for an individual consumer (or group of consumers) the sum of their adjusted profiled demand during their metered period will generally not equal their metered consumption. This difference is referred to herein as the volume error. The retail company will be paying generators for a quantity of consumption that does not equal the metered consumption of the consumers that they supply. However, overall the generators will be paid for the correct total quantity because compensation has ensured that Profile Settlements is balanced in each Accounting Period; that is, the aggregate of the Supplier Charges for generation equals the amount owed to generators.

Difference Profiling does not require the metered consumption of all consumers to be apportioned to Accounting Periods. It is therefore somewhat simpler to implement and operate than Global Profiling, which requires consumption data for all consumers. However, the method of apportionment used in profiling inherently contains significant errors, and when using Difference Profiling, the incumbent retail company is exposed to the aggregate of these errors. There is therefore a trade-off with prior art methods between complexity and the magnitude of errors.

The prior art methods of determining supplier charges, using interval metering or profiling, generally use a further system commonly referred to as the Registration system. The Registration system provides a record of consumers. For the purpose of Profile Settlements the Registration system may contain data regarding each consumer including identifiers for the consumer's

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retailer, the profile to be used to apportion the consumer's consumption and the loss factor to be used. The Registration system can be implemented using a microprocessor based system and the data stored in memory. The data can be illustrated as a table as shown below:

	Retailer identifier	Profile identifier	Line-loss factor identifier
Consumer 1			
Consumer 2			
Consumer 3			
Consumer 4			
Consumer 5			
...			

Table 1

The prior art methods of determining supplier charges generally include a means of adjusting consumption to include an estimate of losses. This adjustment is achieved by using a scalar multiplier, loss factor, which may be a function of time. However, the equipment used, for example, within the electricity distribution network is comprehensively tested to measure its properties including losses and such test results are widely available. Similarly the properties of the cables used for electricity distribution have been characterized and are widely known.

The present invention relates to means to improve the technical operation and accuracy of the second prior art means, namely Profile Settlements.

According to one aspect of the invention there is provided a method of monitoring a network used to supply a commodity to consumers, the network having at least one input supply connection and a plurality of output supply connections, referred to herein as consumers, the method comprising:

determining the difference between two consumption values, referred to herein as the First Consumption and the Second Consumption, where both consumption values relate to the same period, the First Consumption being dependent on the total quantity of the commodity supplied into the network and the Second

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Consumption being derived from the consumption during the period of at least one consumer; and

determining the amount of consumption during a sub-period using a profile, consisting of a set of weightings defining the relative apportionment between sub-periods, and the difference between the First Consumption and the Second Consumption.

According to another aspect of the invention there is provided a method of monitoring a network used to supply a commodity to consumers, the network having one or more input supply connections and output supply connections, referred to herein as consumers, including the metered supply, the method comprising:

using data obtained from metering located at input connections to determine the total quantity of the commodity supplied into the network during a period, the overall demand;

using combinations of metering and apportioning consumption using profiling to determine the consumption during the period for one or more consumers or groups thereof;

determining the total consumption of one or more consumers during the period and subtracting the total consumption from the overall demand; and

using the aggregate result of the subtraction over an extended period to determine the overall error between overall demand and total consumption.

The preferred form of the present invention provides:

- 1 means of determining the collective consumption of a group of one or more consumers without using the individual consumption of those consumers
- 2 means of determining a value of actual losses from the distribution network during a period of time and means of adjusting values of Deemed Consumption for the actual loss; and
- 3 means of adjustment that does not result in the volume errors, referred to above.

An electricity measurement system embodying the invention will now be described, by way of example, with reference to the drawings, in which:

Fig. 1 is a simplified block diagram of a section of an electricity supply network;

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Fig. 2 is a flow diagram of the operation of the measurement system; and Figs. 3 and 4 are block diagrams of parts of the system.

Before describing the system, in detail, the principles on which it operates will be described,

Metering can be used to assess the losses within a particular section of distribution network. For example, all inputs and outputs to a section may be metered using interval metering, and the difference will be the network loss. Such measurement can be used to estimate the loss in similar networks under particular conditions. Also, as noted above, data is available regarding the characteristics of equipment used in networks. In the case of electricity distribution, the losses from a network are largely dependant upon the design and construction of the network, the total demand, and temperature. Using the available data and knowledge, a function can be derived for total loss dependent upon total demand, and this function provides a method of estimating total loss. For example, the function may be expressed based upon the characterization of the various elements of the network. Thus the losses from cable can be a function of overall demand, the cable types, the length of cable, and whether the cables run in parallel (thereby reducing the power supplied through each). The losses from transformers and other equipment can be a function of demand and the number of transformers,

Where the data or knowledge associated with a particular section of network is insufficient to determine an accurate function to define total loss, and where there are no comparable networks, the function can simply be based upon estimated loss factors and aggregate or relative consumption attributable to each loss factor.

Using the prior art, it is possible to determine the Overall Demand, also referred to herein as O, and using interval metering or profiling it is possible to determine a value of deemed consumption for each consumer for an Accounting Period. Such values of deemed consumption also being referred to herein as C,

The Total Consumption is determined for each Accounting Period by aggregating the deemed consumption during the Accounting Period of all consumers. Thus:

$$\text{Total Consumption} = \sum C \quad (1)$$

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However, for the purpose of determining Total Consumption the present system can exclude, or mask, the consumption of some consumers, referred to herein as the Excluded Consumers.

Table 2 below is used to illustrate an implementation of the present system using a suitable microprocessor based system. For example, a daily value of deemed consumption can be determined for each consumer using interval metering or profiling. This data can be recorded, say, in the form of a table in the memory of a microprocessor based system.

The example illustrated in this table is based upon an Extended Period of a week. Whilst data may be recorded on, say, a daily basis, the system may further apportion this using profiling to Accounting Periods that are shorter, for example half-hourly.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Week Total
Consumer 1								
Consumer 2								
Consumer 3								
Consumer 4								
Consumer 5								
Consumer 6								
Overall Demand								

Table 2

Patent application WO 97/06442 provides various technical benefits by using rate of consumption data for the purpose of Profile Settlements. The present system can utilize rates of consumption as a means of achieving technical benefits and efficiency within the implementation of the system. For example, the rate of consumption can be stored on a daily basis and such values can be aggregated as described in WO 97/06442. The aggregate rate of consumption can then be used to produce deemed consumption for one or more consumers. The description herein of the present invention is based upon using values of

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deemed consumption. However, all of the prior art methods of profiling can be utilized where appropriate including using rates of consumption.

The system may not contain data relating to any Excluded Consumers and they will therefore be ignored as far as the present system is concerned. For example, in the above illustration there may be a Consumer 7 which is an Excluded Consumer and is therefore not included within the system. Alternatively the system may contain data relating to some or all Excluded Consumers and the consumption of these Excluded Consumers will be ignored, or masked, when determining the Total Consumption. This can be achieved, for example, by extending the Registration System to include data to indicate whether or not a particular consumer is an Excluded Consumer. The present system then aggregates deemed consumption during the Extended Period for all consumers other than Excluded Consumers.

Rather than, or in addition to, modifying the Registration system, the present system can simply mask the deemed consumption of Excluded Consumers for those periods that they were Excluded Consumers. This enables the consumers to change retailer, which may affect whether or not they are an Excluded Consumer. Thus, in Table 2 deemed consumption would be masked or set to 0 for those periods when a consumer was an Excluded Consumer. The Registration system may then be modified to include data to indicate whether each consumer is an Excluded Consumer at the current time. Alternatively it may be possible to derive this from existing information such as information regarding each consumer's retailer, profile, and metering arrangements. The system can then record each consumer's status, that is whether or not they were an Excluded Consumer, in a table having similar structure to Table 2. Alternatively, Table 2 can record both status and deemed consumption.

The system also produces Group Demand, also referred to herein as G , by aggregating consumption for a defined group of consumers. For example, a group referred to as g can be defined and the deemed consumption during an Accounting Period of consumers in group g aggregated. The Group Demand in the i th Accounting Period can be expressed as:

$$G_i^g = \sum_{j \in g} C_{i,j} \quad (2)$$

where $C_{i,j}$ is the deemed consumption during the i th Accounting Period for consumer j and where the summation is performed for all consumers in group g .

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This can be extended such that part of a particular consumer's consumption is included within Group Demand rather than the whole. Thus a value can be defined within the system, herein referred to as P, that is the fraction of C, the deemed consumption, that is used to produce a particular value of Group Demand. P could, for example, be 0.5. Group Demand, for group g, can then be expressed as:

$$G_i^g = \sum_{j \in g} (C_{ij} \times P_{ij}^g) \quad (3)$$

Note that a plurality of different, possibly overlapping, groups can be defined in the present system and Group Demand determined for each. In all of the above methods, deemed consumption can be an adjusted value including an estimated value of loss. In such circumstances the deemed consumption equals the unadjusted consumption multiplied by the appropriate loss factor.

Rather than solely considering Accounting Periods, the present system provides various technical advantages compared to the prior art by also considering Extended Periods, for example weeks or months. Overall Demand and Total Consumption can be determined for the same period and the difference, referred to herein as the Remaining Consumption, determined. The present system can determine the Remaining Consumption both for Accounting Periods and for Extended Periods.

The first part of the present system provides a method of achieving much of technical and operational simplicity of Difference Profiling whilst removing the main errors inherent in Difference Profiling, such that the system is comparable to Global Profiling in terms of accuracy. This is achieved by determining the Supplier Charge for the consumption of the Excluded Consumers on a collective basis rather than using their individual consumption.

Global Profiling would require all consumption to be used within Profile Settlements. The present system excludes some consumers, that is the Excluded Consumers, from Total Consumption, determines Remaining Consumption for an Extended Period and then determines the collective consumption of the Excluded Consumers, referred to herein as the Excluded Consumption, using the Remaining Consumption.

The present system includes two methods of determining the Excluded Consumption.

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First, the system uses the aggregate Remaining Consumption during the Extended Period as the Excluded Consumption, and in the preferred embodiment the Total Consumption is producing using loss adjusted values of deemed consumption. Using this method, the Excluded Consumption is the deemed Consumption for the Excluded Consumers, and inherently a portion of the Excluded Consumption represents loss. A ratio can be defined to determine what portion of Excluded Consumption is loss and what portion is consumption by consumers. Thus, if the ratio is 1:19, or 0.05, the loss would be regarded as 5% of the Excluded Consumption and the actual consumption would be 95%.

Second, the Total Loss is determined using a function of Overall Demand, and the Excluded Consumption determined by subtracting Total Loss and Total Consumption from Overall Demand. In the second method, Total Consumption for the purpose of determining Excluded Consumption should not include estimates of loss. If the second method is used to determine Excluded Consumption, then, once Excluded Consumption has been determined, an estimated value of loss can be added to the Excluded Consumption and the deemed consumption for other consumers. Such loss adjustment could, for example, use a scalar loss factor.

Thus, using Table 2, the consumption of Consumer 1 to Consumer 4 inclusive may be used in Profile Settlements and Consumer 5 and Consumer 6, say, are Excluded Consumers. Using extended periods of, say, one week, the aggregate Overall Demand, Total Consumption - that is the loss adjusted consumption of Consumers 1 to 4 - and Remaining Consumption are determined. The Remaining Consumption for the Extended Period is then used as the collective consumption during the extended period of Consumer 5 and Consumer 6 - the Excluded Consumers. Using the alternative method, the Total Consumption excluding loss and the total loss are determined and subtracted from Overall Demand during the Extended Period. The result is the consumption of the Excluded Consumers, which can, if appropriate, be adjusted to include an estimate of loss, for example using a loss factor, in order to produce Excluded Consumption.

Using a profile for the Excluded Consumers together with the Excluded Consumption enables a deemed consumption to be produced for them collectively for each Accounting Period. The system does not require data for the individual consumption of the Excluded Consumers. By dealing with the Excluded Consumers collectively, the system achieves significant technical and operation efficiencies. If the Excluded Consumption during the Extended Period does not

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include loss, then the apportioned consumption in each Accounting Period can be adjusted for using a loss factor.

Determining and using Excluded Consumption during an Extended Period to represent the collective consumption of the Excluded Consumers significantly reduces the technical and operation complexity of Profile Settlements. It is convenient for the Excluded Consumers to be all of those consumers supplied by one retailer, particularly the dominant retailer. Additionally the Excluded Consumers may be limited to those consumers allocated with a particular profile or those having a particular combination of profile and metering arrangements.

If all Excluded Consumers belong to a single profile class- that is, if they are all allocated to the same profile in Global Profiling - then the profile used to apportion Excluded Consumption can be the profile that would be used to apportion each consumers' individual consumption. This may be defined in the Registration system. If the Excluded Consumers are consumers that would be allocated a variety of different profiles, then a single composite profile can be produced for the Excluded Consumers collectively by a variety of means including:

- 1 metering one or more sections of distribution network that each or collectively supply the Excluded Consumers or a similar group of consumers and deriving the profile from the resulting metered data; or
- 2 load research and/or statistical sampling in order to construct an appropriate profile; or
- 3 identifying the different profile classes within the group of Excluded Consumers (for example by reference to the Registration system), estimating the relative consumption of each class during the Extended Period, and producing the composite profile as the weighted average of the profiles associated with each profile class; or
- 4 any combination of the above.

Different Excluded Consumers may be in different profile classes. Also, whether or not a particular consumer is an Excluded Consumer may depend upon dynamic factors such as which company is their retailer. Thus, the number of Excluded Consumers may vary, say, day-to-day, and whether a particular consumer is an Excluded Consumer may vary.

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If profiles are expressed as a set of profile weightings, W , where $W_{i,p}$ is the weighting for the i th Accounting Period for profile p , and a profile is available for each profile class then the profile used to apportion the Excluded Consumption can be produced by the present system using this information. For example, a value E can be defined for a period for each Excluded Consumer and the profile weighting for the i th Accounting Period determined using:

$$\text{Excluded Consumer profile weighting} = \sum_{\substack{p = \text{all} \\ \text{profile} \\ \text{classes}}} \left(\frac{W_{i,p} \times \sum_{j=x} E_{i,j}}{\sum_{k=0} W_{k,p}} \right) \quad (4)$$

where the summation over $j=x$ determines the aggregate value of E for all consumers in profile class p and the overall summation is for all values of p , that is for all profile classes. The values of E can be 1 or they can be a relative estimate of each consumer's consumption or a relative estimate of class average consumption.

The summation in the denominator determines the aggregate profile weighting for profile p during the period of E . Thus if E is recorded for each Excluded Consumer per day, then the summation would be over the day containing the i th Accounting Period. Conveniently E can be determined by recording in Table 2 an estimate of deemed consumption for Excluded Consumers, which is masked when determining Total Consumption, and using the estimate of deemed consumption as E . This can be implemented, for example, by the system including data to specify whether each cell in Table 2 is a value of deemed consumption for a non Excluded Consumer or whether the consumer is an Excluded Consumer and whether the data in the cell is a value for E .

The system will produce the Excluded Consumption for the Extended Period, from which it can determine the Excluded Consumption in an sub-period, including Accounting Periods, using the profile for the Excluded Consumers to apportion the consumption to Accounting Periods. If all Excluded Consumers are supplied by a single retailer, then a Supplier charge can then be determined using this collective value of consumption and the relevant price.

The apportionment is performed by multiplying the Excluded Consumption by the Excluded Consumer's Profile Weighting for an Accounting Period and dividing by the aggregate weighting for the Extended Period.

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The Excluded Consumption can be sub-divided into a number of parts, for example between a plurality of retailers. The division can be based on the relative consumption of each part. Thus, the Excluded Consumption can be divided between retailers on the basis of the aggregate value of E for the Excluded Consumers that each retailer supplies. This can be performed for each Accounting Period, or for the Extended Period as a whole prior to apportioning the consumption to the Accounting Periods.

When using profiling, it is not possible to measure the loss from the distribution network by considering a particular Accounting Period. Also, the fact that the metered periods for different consumers vary considerably means that it is not possible to measure the loss in a metered period common to all consumers.

In the case of electricity, errors within Profile Settlements include:

- 1 errors in the estimate of electrical losses from the network,
- 2 theft,
- 3 metering errors,
- 4 errors in the apportionment of consumption to Accounting Periods,
- 5 errors caused by the time of meter readings being rounded or approximated,
- 6 errors in the synchronisation of meters, and
- 7 errors resulting from the fact that, with simple metering, different consumers will have different metered periods.

The present system determines a value, referred to herein as Measured Loss, which is an estimate of the difference between the actual loss and the estimate of loss already included in values of deemed consumption. It should be noted that if the consumption of a group of consumers is estimated by whatever means outside the present system, for example by using the cumulative quantity of the commodity that the retailer charges to the consumers that they supply in a particular profile class, then that group of consumers are not considered by the present system to be Excluded Consumers. Rather the group would be dealt with as a single consumer for which metered consumption is provided.

Over an extended period, for example a week or a month, the above errors will tend to cancel with the exception of errors 1 to 3. However, error 3, that

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is metering errors, will tend to cancel over a large number of consumers unless there is a consistent bias in the metering.

The Measured Loss is the difference during an Extended Period between Overall Demand and the aggregate deemed consumption for all consumers including Excluded Consumers. The Actual Loss during the Extended Period is the Measured Loss plus any estimate of loss included in values of deemed consumption. If there are no Excluded Consumers, then the Measured Loss will equal the Remaining Consumption.

As already stated, a function of Overall Demand can also be used to estimate overall loss. For an extended period, the overall loss determined using such a method will be an estimate. It can therefore be compared to the Actual Loss during the Extended Period and used to estimate the actual overall loss in an Accounting Period using:

$$\text{Actual Overall Loss}_i = f(O_i) \times \frac{\left(ML_{op} + \sum_{k=op} EL_k \right)}{\sum_{j=op} f(O_j)} \quad (5)$$

where ML is the Measured Loss during an Extended Period, EL is the estimated loss included in deemed consumption, $f(O_i)$ is the function of Overall Demand in the i th Accounting Period, and both summations are over the Extended Period.

The present system enables the Actual Loss to be accounted for within the system by any combination of two methods. First, loss can be apportioned to one or more virtual consumers. Second, loss can be apportioned between a defined group of consumers.

The function of Overall Demand, $f(O)$, can be regarded as a profile defining the apportionment of loss between Accounting Period. Thus, a profile, for example derived from the function of Overall Demand, can be used to apportion actual loss or measured loss to Accounting Periods. A profile to apportion Measured Loss may be positive or negative in any period; that is, the profile may reflect the fact that the initial adjustment for loss may have over estimated the loss. For example, the profile weighting in an Accounting Period for such a profile can be determined using:

$$f(O_i) \times \frac{\sum_{k=op} (ML_k + EL_k)}{\sum_{j=op} f(O_j)} - EL_i \quad (6)$$

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Loss can be regarded within the present system as consumption by one or more virtual consumers. Thus Table 2 can be extended to include a virtual consumer representing some or all of actual loss as shown below.

	Week							Total
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	
Consumer 1								
Consumer 2								
Consumer 3								
Consumer 4								
Consumer 5								
Consumer 6								
Virtual Consumer								
Overall Demand								

Table 3

The Virtual consumer's consumption in the Extended Period will be all or part of the Actual Loss for the Extended Period and, for example, may be the Measured Loss or that portion, if any, of the Actual Loss above a defined level. Its consumption in each sub period will be the amount apportioned using the appropriate profile. The present system supports multiple virtual consumers.

Alternatively, the virtual consumer's consumption can be determined in each Accounting Period. For example, the virtual consumer's consumption can be that portion of actual overall loss in the Accounting Period above a defined level. That level may be a constant or may be a function of certain variables including demand and time.

A charge can be determined for the virtual consumer's consumption. If a company, for example the company owning the distribution network, is responsible for the efficiency of the delivery, then they may pay this charge. Thus, they may be charged for all or part of the Measured Loss. For example, a permitted value of loss can be defined as a function of certain variables including demand, the actual loss in the same period compared to the permitted loss, and, if actual

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loss is greater than the permitted loss, the difference may be charged, say, to the distribution network owner.

Alternatively, the system can determine a charge to a retail company based upon a virtual consumer's consumption. Thus the difference between the actual overall loss in an Accounting Period and the estimated loss already included in values of deemed consumption may be apportioned, either in whole or in part, between retailers in proportion to, say, their consumers' consumption or the number of consumers supplied.

These methods may be combined. For example, the consumption of a virtual consumer may be determined, say, using the amount of actual loss in each Accounting Period above a threshold, and the remainder of the loss that is not already included in deemed consumption may then be apportioned between retail companies as described above. Thus the amount of loss so apportioned will be the actual overall loss minus loss included in deemed consumption include the consumption of Excluded Consumers and Virtual Consumers.

Alternatively, the present systems includes a method of adjustment to adjust the deemed consumption of one or more consumers. A group can be defined such that the corresponding value of Group Demand is the consumption that should be adjusted by the system. The present system can perform that adjustment either for each Accounting Period or over the Extended Period.

The present system determines a Loss Value, also referred to herein as V. In the preferred embodiment the Loss Value is the difference between the actual overall loss and the aggregate loss included in the deemed consumption of all consumers, including the loss attributed to virtual consumers and loss charged to retailers and others.

The Loss Value can be determined for each Accounting Period or it can be determined for an Extended Period and a suitable profile used to apportion it to Accounting Periods. In each Accounting Period, the deemed consumption constituting the Group Demand can then be adjusted in aggregate by an amount equal to the apportioned Loss Value. For example, for a consumer x:

$$\text{Adjustment} = \frac{V_i \times (C_{i,x} \times P_{i,x}^s)}{\sum_{j \in s} (C_{i,j} \times P_{i,j}^s)} \quad (7)$$

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or alternatively

$$\text{Adjustment} = \frac{V_i \times (C_{i,x} \times P_{i,x}^s \times (L_{i,x} - 1))}{\sum_{j=g} (C_{i,j} \times P_{i,j}^s \times (L_{i,j} - 1))} \quad (8)$$

where V_i is the Loss Value in the i th Accounting Period. These adjustments are added to the consumer's deemed consumption.

The adjustment can also be determined using the Loss Value for the Extended Period. This is achieved, for example, by adding to the consumer's consumption in each Accounting Period within the Extended Period, for example the i th period, a value equal to the consumer's deemed consumption in the Accounting Period multiplied by the Loss Value and divided by Group Demand for the Extended Period. This can be expressed as:

$$\text{Loss Corrected Consumption} = C_{i,x} + \frac{V \times (C_{i,x} \times P_{i,x}^s)}{\sum_{k=e} \left(\sum_{j=g} (C_{k,j} \times P_{k,j}^s) \right)} \quad (9)$$

where e is the Extended Period, g is the group defining the consumption to be adjusted, x is an index for the individual consumer, and C is the deemed consumption. If the Total Consumption is determined using loss adjusted consumption, then in equation 9 the three uses of deemed consumption are similarly adjusted for loss.

Alternatively:

$$\text{Loss Corrected Consumption} = C_{i,x} + \frac{V \times C_{i,x} \times P_{i,x}^s \times (L_{i,x} - 1)}{\sum_{k=e} \left(\sum_{j=g} (C_{k,j} \times P_{k,j}^s \times (L_{k,j} - 1)) \right)} \quad (10)$$

Since the Loss Value and the denominator are common to all consumers, an implementation can achieve some optimization by determining a Loss Adjustment Factor for each Extended Period by dividing the Loss Value by the denominator in equations 9 or 10. The method of determining each value of Loss Corrected Consumption can then be simplified to utilise the common Loss Adjustment Factor.

The method of adjustment can be modified to apportion the Loss Value in a manner other than that defined by the consumers deemed consumption. For example, as described above, research and test data may be available for the losses incurred in the electricity distribution network and this data may include characterization of the equipment, such as transformers and cable, used in the distribution network. From this data, it is possible to determine the relative

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loss from the network as a function of overall demand and other factors (for example temperature) rather than as a function of consumer's deemed consumption alone. For example, equation 9 can then be modified to:

$$\text{Loss Corrected Consumption} = C_{i,x} + \frac{V \times \sum_{k=0}^n (C_{k,x} \times P_{k,x}^s)}{\sum_{k=0}^n \left(\sum_{j=0}^n (C_{k,j} \times P_{k,j}^s) \right)} \times f(i) \quad (11)$$

where $f(i)$ is a function that when summed over the Extended Period should be unity. Equation 10 can be similarly modified. The numerator in the equation can also be modified so that consumers do not simply incur a responsibility for the Loss Value in proportion to their consumption. This can be generalized as:

$$\text{Loss Corrected Consumption} = C_{i,x} + f(V,C,G) \times f(i) \quad (12)$$

where $f(V,C,G)$ is a function of the Loss Value, the consumer's consumption and the Group Demand.

A benefit of equations 9, 10 and 11 is that Loss Corrected Consumption can be determined for each consumer and the definition of the group, used to determine the values of P , will determine whether an actual adjustment is made to the deemed consumption.

Using the various methods described thus far results in the aggregate of all consumption including loss adjustment and correction during the Extended Period being equal to the Overall Demand during the period.

However, the above methods of using Remaining Consumption do not result in a situation where the aggregate consumption for all consumers, including any Excluded Consumers, in a single Accounting Period equals the Overall Demand for that period. The present system therefore includes means to further adjust the values of profiled consumption.

The present system determines the Period Error for an Accounting Period by subtracting the aggregate consumption including loss of all consumers, including any Excluded Consumers, from the Overall Demand. The aggregate of the Period Error during the above Extended Period should be 0 if the above methods have been used. If it is not 0 then the aggregate value of Period Error can be considered to be the consumption during the Extended Period of a virtual consumer and dealt with as already described. The Period Error can then be recalculated for each Accounting Period and in aggregate will be 0 during the Extended Period.

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The present system includes a method of two-stage error adjustment. The first stage includes means to produce an Initial Adjustment Factor for an Accounting Period by dividing the Period Error by Group Demand. The consumption constituting the Group Demand is then multiplied by the Initial Adjustment Factor to determine the adjustment which is then added to the consumption. Thus adjusted consumption, C_a , is:

$$C_{a,i,x} = C_{i,x} \times (1 + IAF \times P_{i,x}) \quad (13)$$

If P is 1, then the multiplier $(1 + IAF \times P)$ can be determined by dividing the sum of Period Error plus Group Demand by Group Demand.

The Group Demand is produced using the same consumption data as that used to determine the Period Error. The Group Demand may also include the Remaining Consumption or part thereof, for example where there are Excluded Consumers. Thus where there is Excluded Consumption, a value of P can be defined for the Excluded Consumption.

This first stage of error adjustment results in the same problem as the prior art means of compensation, namely that adjusted consumption for an individual consumer no longer represents their metered consumption. However, the second stage of adjustment includes means to determine and correct the volume error.

The method of determining the volume error considers an extended period of time, for example a day, week or month, referred to herein as the Compensation Period. The Compensation Period may not be a continuous period. There is no requirement that the Extended Periods used to determine loss should equate to Compensation Periods; however, it may be practical in a particular implementation for this to be so, and there would be technical benefits.

The volume error that would be caused by the first stage of adjustment can be determined using the equation:

$$\text{Error}_x = \sum_{\substack{j \\ \text{Compensation} \\ \text{Period}}} (C_{j,x} \times IAF_j \times P_{j,x}) \quad (14)$$

A credit or charge can be determined using the Error and a price, for example a weighted average of the prices during the Compensation Period. Alternatively, the adjusted consumption during the Compensation Period following the first

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stage of adjustment can be further adjusted by an amount equal to the Error - this is the second stage of adjustment.

The consumption during the Compensation Period can be adjusted by an amount equal to the Error by using a profile to apportion the Error to Accounting Periods and subtracting the apportioned amount from the adjusted consumption in the period. Thus, the consumption after both stages of adjustment, referred to as K, is expressed as:

$$K_{i,x} = Ca_{i,x} - \frac{\text{Error}_x \times EP_i}{\sum_{\substack{j \\ \text{Compensation} \\ \text{Period}}} EP_j} \quad (15)$$

where EP represents the weightings for the profile, the Error Profile, used to apportion the error.

If the same Error Profile is used for all consumers, then the system will remain balanced both within Accounting Period and, if the Compensation Period equals the Extended Period, during the Compensation Period. One method of producing an Error Profile for all consumers is for the Error Profile to equal Group Demand or a normalised version of Group Demand. Alternatively:

$$EP_i = \sum_j \left(\frac{\text{Error}_j \times W_i}{\sum_{cp} W} \right) \quad (16)$$

where W is the profile weighting for consumer j, the overall summation is over all consumers, and the denominator is the summation of the profile weightings over the Compensation Period, cp. In equation 16 Error will be 0 for those consumers not within the group whose consumption was used to determine Group Demand, that is where P is 0.

Where one or more consumers do not have continuous consumption during the Compensation Period, or where consumption is recorded in a plurality of registers, then the Error Profile weighting in an Accounting Period can be 0 where no consumption occurred. Similarly, for a particular consumer, the Compensation Period may encompass a plurality of metered periods and the Error Profile weightings for that consumer can be adjusted to reflect their relative consumption during each metered period. The present system may also use different Compensation Periods for different consumers.

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If the Error for one or more consumers is apportioned using one or more Error Profiles, then the aggregate of the adjustments made can be used to produce the error profile for other consumers. The aggregate of the adjustments in an Accounting Period is expressed by the sum of:

$$\frac{\text{Error}_x \times \text{EP}_i}{\sum_{\substack{j= \\ \text{Compensation} \\ \text{Period}}} \text{EP}_j} \quad (17)$$

This method can be used iteratively.

Referring now to Fig. 1, a section of an electricity supply network is shown, consisting of transformer substations T and cabling connecting a plurality of metered inputs to consumers shown in the diagram as numbered boxes. This section of network is monitored using appropriate metering.

Fig. 2 is a flow chart of the operation of the present system, embodying all of the methods described above. The Overall Demand is determined using Interval metering at inputs to the network. Consumer consumption is determined using interval metering at consumers, profiling, or a combination of both. For example, a table such as shown in Table 2 can be used in a microprocessor based system to record the consumption for each consumer except those consumers where interval metering is used. Such data can be recorded for say daily periods. The table, or a table having similar structure, can also record whether consumers are Excluded Consumers.

Alternatively, the system described in WO 97/06442 provides methods of using rates of consumption that can be used within the present system to provide further benefit. Such a system will record the rate of consumption in the table and enable data for several consumers to be aggregated prior to converting the aggregate to an aggregate value of consumption. The rate of consumption is determined for a consumer by dividing their metered consumption by the aggregate of the profile weighting during their metered period, and this rate of consumption is recorded for each period in the metered period. A rate of consumption, or aggregate rate of consumption, is then converted into a value of consumption by multiplying it by the profile weighting in the period.

Having used metering and profiling to produce Overall Demand and deemed consumption, the Overall Demand is determined for the Extended Period. The

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demand consumption of consumers other than Excluded Consumers is also determined for the Extended Period.

The operation of the present system is then dependent on whether there are Excluded Consumers and, if so, the method by which the Excluded Consumption is determined. Using the first method, the total consumption includes an estimate of loss, and the Excluded Consumption is the Overall Demand for the Extended Period minus the total consumption for the Extended Period. Using the alternative method, the total consumption does not include an estimate of loss, and the Excluded Consumption is the Overall Demand for the Extended Period minus the total consumption for the Extended Period and the estimated overall network loss.

Once the Excluded Consumption has been determined, it can be apportioned to the Accounting Periods using the appropriate profile, for example derived using equation 4. If the alternative method is used or if there are no Excluded Consumers, then the Measured Loss is determined and the loss apportioned either to virtual consumers or by correcting values of consumption, for example using equations 7 to 12.

The system then measures the Period Error and performs the first stage of adjustment. The volume error is then measured and the consumption further adjusted for the Error, for example using equation 15.

The initial parts of the system are shown in Fig. 3. Interval metering by unit means 100 located at inputs to the network is used to measure the volume supplied into the network during each Accounting Period. This data is used to produce Overall Demand, which is recorded in unit means 200. Unit means 300 aggregate Overall Demand data to provide the Overall Demand for an Extended Period.

Metering by unit means 101 is used at consumers, and the metered data is used to record consumption or rate of consumption for each consumer in unit means 201. Unit means 301 produce the total consumption for the Extended Period.

Unit 302 determines the Excluded Consumption using either of the methods described above. Where the alternative method is used, the unit 302 may use

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Overall Demand data recorded in unit means 200 to produce the amount of overall loss.

The Excluded Consumer Profile is derived by unit 303, for example using equation 4, and unit 304 apportions the Excluded Consumption to Accounting Period using the profile.

Fig. 4 shows the parts of the system for adjusting consumption. Unit 305 records the deemed consumption for consumers, or groups of consumers, in each Accounting Period. Unit 309 defines a group of consumers and the associated values of P. Unit 308 produces the group demand using the information from unit 309 together with the deemed consumption from unit 305. Unit 306 determines the period error for each Accounting Period. Unit 307 then produces the initial adjustment factor by dividing the period error from unit 306 by the group demand from unit 308.

Unit 310 multiplies the initial adjustment factor from unit 307 by the values of P from unit 310. Together with deemed consumption from unit 305, this is used by unit 311 to produce the adjusted consumption, Ca.

Unit 312 determines the volume error during a Compensation Period, for example by using equation 14 or by measuring the difference between deemed consumption from unit 305 and the adjusted consumption from unit 311. Unit 313 produces the final consumption using equation 15 together with the appropriate error profile.

In summary, the system monitors the supply of electricity using a physical distribution system consisting of at least one input and a plurality of outputs and determining the deemed consumption of one or more outputs during a period. The the overall demand, that is the total commodity supplied into the network, during an extended period, and the deemed consumption of outputs during the same extended period, are determined. The system further determines the deemed consumption during an extended period of a group of outputs without reference to the individual consumptions of those outputs. The system apportions the deemed consumption of outputs, including groups of outputs, to sub-periods of the extended period and adjusts the apportioned consumption without causing a cumulative error over the extended period, such that the aggregate deemed consumption in any one sub-period equals the overall demand in that sub-period.

Claims

- 1 A method of monitoring a network used to supply a commodity to consumers, the network having at least one input supply connection and a plurality of output supply connections, referred to herein as consumers, the method comprising:

determining the difference between two consumption values, referred to herein as the First Consumption and the Second Consumption, where Both consumption values relate to the same period, the First Consumption Being dependent on the total quantity of the commodity supplied into the network and the Second Consumption Being derived from the consumption during the period of at least one consumer; and

determining the amount of consumption during a sub-period using a profile, consisting of a set of weightings defining the relative apportionment between sub-periods, and the difference between the First Consumption and the Second Consumption.
- 2 A method according to claim 1 wherein the First Consumption is the total quantity of the commodity supplied into the network during the period minus the estimated overall loss from the network.
- 3 A method according to claim 1 wherein the First Consumption is an adjusted value of the Second Consumption, the adjustment Being dependent on the total quantity of the commodity supplied into the network during each sub-period (equation 13 or 14).
- 4 A method according to either previous claim wherein the profile used is derived using a weighted average of the profiles allocated to each of the consumers. (equation 4 or 16).
- 5 A method according to claim 1 wherein the First Consumption is the total quantity of the commodity supplied into the network during the period and the Second Consumption is the consumption during the period of all consumers supplied from the network (eg equation 6).
- 6 A method according to either of claims 1 and 5 wherein the amount of consumption during the sub-period is the value of the difference between the

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First Consumption and the Second Consumption apportioned to the sub-period that is in excess of a predetermined level.

7 A method according to any of claims 3, 5, and 6 wherein the consumption of on or more consumers is adjusted by the amount of consumption during the sub-period (equations 7-12 and 15).

8 A method of monitoring a network used to supply a commodity to consumers, the network having one or more input supply connections and output supply connections, referred to herein as consumers, including the metered supply, the method comprising:

using data obtained from metering located at input connections to determine the total quantity of the commodity supplied into the network during a period, the overall demand;

using combinations of metering and apportioning consumption using profiling to determine the consumption during the period for one or more consumers or groups thereof;

determining the total consumption of one or more consumers during the period and subtracting the total consumption from the overall demand; and

using the aggregate result of the subtraction over an extended period to determine the overall error between overall demand and total consumption.

9 A method according to claim 8 in which the overall error is used as the collective consumption of one or more consumers and in which this collective consumption is apportioned to sub periods of the extended period using a profile consisting of a number of profile weightings define the relative apportionment between sub periods.

10 A method according to claim 8 in which the overall error is apportioned between and added to the consumption, during the periods in the extended period, of one or more consumers.

11 A method according to any of claims 8 to 10 in which an adjustment is made to the consumption of one or more consumers using an adjustment factor determined using the overall demand and the consumption of all consumers.

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12 A method according to claim 11 in which the volume error caused by the adjustment over an extended period is determined using the consumption and adjustment factor.

13 A method according to claim 12 in which the volume error is apportioned to periods and subtracted from the consumption.

14 Any novel and inventive feature or combination of features specifically disclosed herein within the meaning of Article 4H of the International Convention (Paris Convention).

1/2

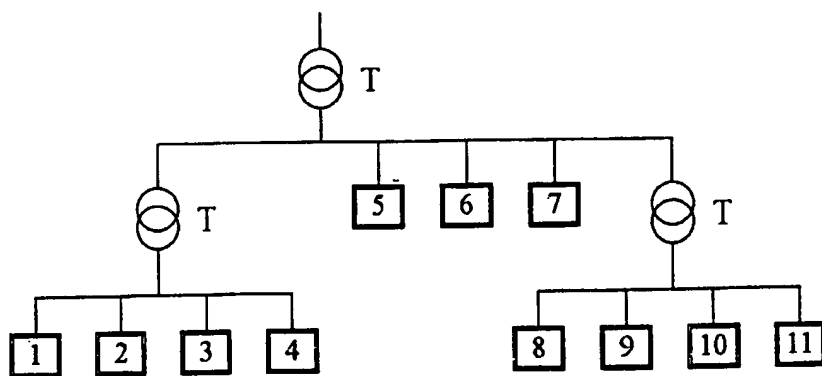


Figure 1

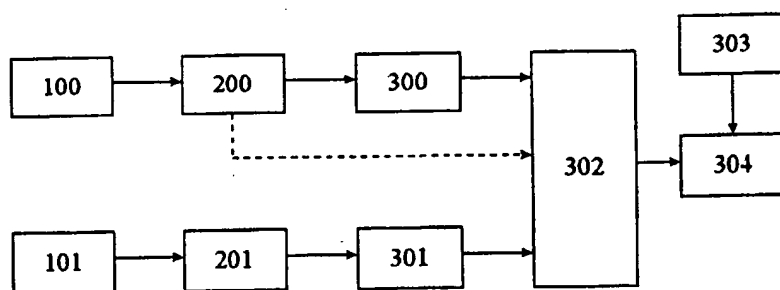


Figure 3

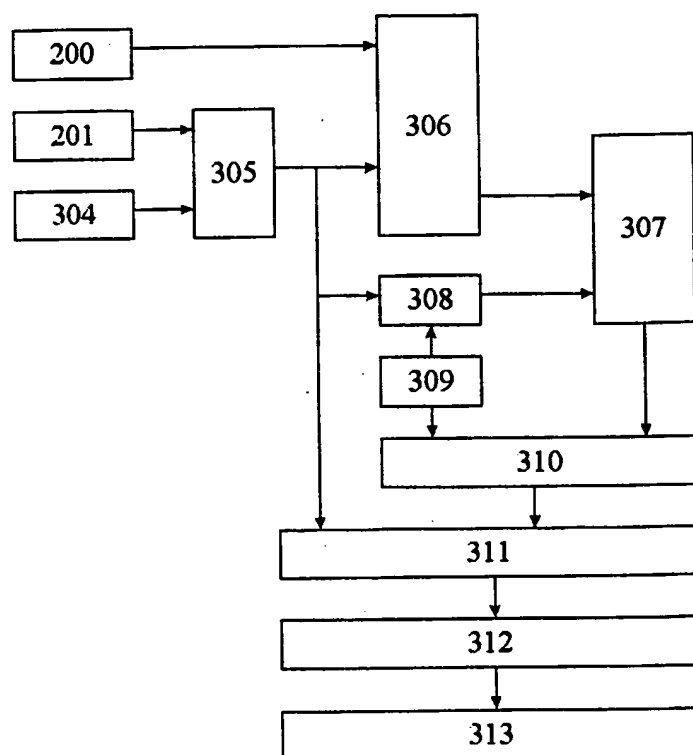


Figure 4

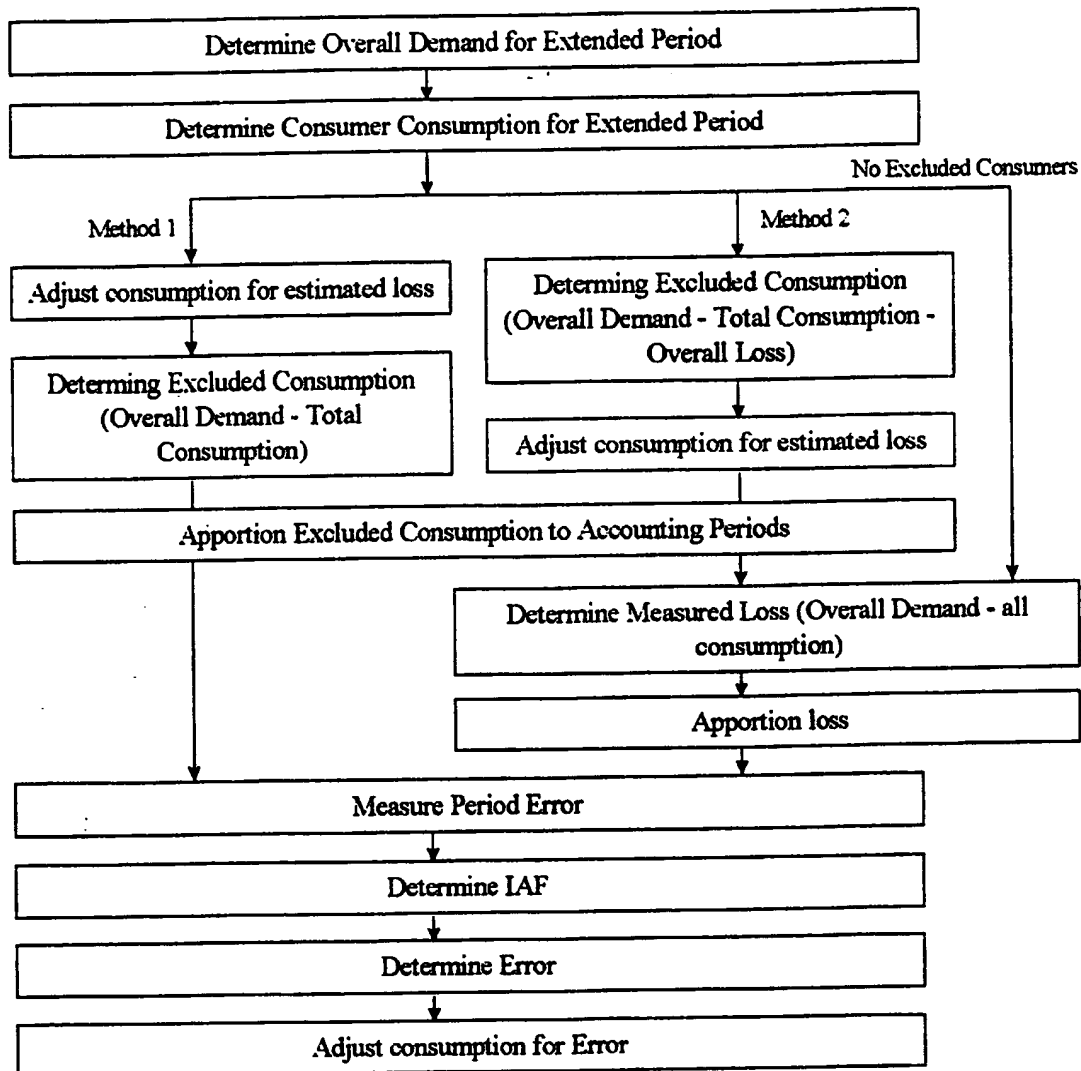


Figure 2

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 98/02186

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01R21/133

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 97 06442 A (OPTIMUM SOLUTIONS LTD ; WILLIAMS PAUL NICHOLAS (GB)) 20 February 1997 cited in the application see the whole document	1,8
A	WO 95 26065 A (OPTIMUM SOLUTIONS LTD ; WILLIAMS PAUL NICHOLAS (GB)) 28 September 1995 cited in the application see the whole document	1,8

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"B" document member of the same patent family

Date of the actual completion of the international search

25 November 1998

Date of mailing of the international search report

12.01.99

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/GB 98/ 02186

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 14
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
Claim 14 is unclear about the matter for which protection is sought. See also PCT Art.6.

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

...formation on patent family members

International Application No

PCT/GB 98/02186

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9706442 A	20-02-1997	AU 6706196 A CA 2229047 A	05-03-1997 20-02-1997
WO 9526065 A	28-09-1995	AU 693870 B AU 1954795 A CA 2186030 A EP 0761032 A NZ 282440 A	09-07-1998 09-10-1995 28-09-1995 12-03-1997 26-08-1998